Advanced Multistage Turbine Blade Aerodynamics, Performance, Cooling, and Heat Transfer

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Abstract

To improve the design capability for high temperature turbines, a detailed understanding of the highly unsteady and three-dimensional flow through multistage turbines and its interaction with heat transfer is necessary. The overall objective of this experimental research program is to improve the design capability for high-temperature turbines by providing a thorough, detailed understanding and data base of turbine flow fields and their effect on heat transfer. In particular, the objective is to experimentally investigate the fundamental three-dimensional and unsteady flow and heat-transfer phenomena that control the performance of advanced turbines. This research program investigates and quantifies the detailed three-dimensional and unsteady flow through the first stage, as well as the detailed unsteady heat transfer caused by vane-wake interaction.

The technical approach is directed at obtaining fundamental data, both steady and unsteady, to quantify the fundamental turbine-flow and heat-transfer phenomena inherent in high-performance, high-efficiency, multistage turbines. A key requirement for these experiments is the facility itself. Experiments directed at the quantitative study of turbine aerodynamics, performance, and heat transfer require that both the unsteady flow and the fundamental interactions of the unsteady flow with the inherently three-dimensional turbine flow field be experimentally simulated. Thus, this experimental research is performed in the Purdue Turbine Research Facility, a two-stage, low-speed turbine that produces the essential aspects of the steady and unsteady flow fields inherent in high-speed multistage turbines.

The unsteady flow through the multistage research engine is accomplished by means of Particle Image Velocimetry (PIV), a measurement technique that provides instantaneous whole-field high-resolution velocity field data. In addition, three-wire thermal anemometry and fast-response pressure probes are also employed. Both fixed and rotating frame data are acquired. Taking advantage of the high-frequency response of thin-film sensors, the blade surface unsteady heat-transfer measurements are made using constant-temperature anemometry and platinum hot-film surface sensors.

This presentation will focus on recent progress made under this program. Specifically, data from PIV characterization of vane-blade interaction will be presented. Data will include

span-wise variation of the flow field approaching the first rotor, as well as a history of the blade-pass event on the region between the first vane trailing edge and the first rotor blade. This PIV data has captured the significant effect the blade-vane potential field has on the upstream flow field and rotor instantaneous incidence, as well as the character of the vane wake as it is influenced by this flow field.

In addition, rotating frame measurements obtained using three-wire thermal anemometry and a miniature unsteady total pressure probe will be presented. This data provides information that completes the definition of the aerodynamic forcing functions acting on the rotor blade row aerodynamics and unsteady heat transfer. The data completely define the 3-D pressure, velocity, and stagnation pressure distribution as the rotor inlet and exit. The data also illuminate passage secondary flows.

In the closing part of this program, the measurements on the facility will conclude with the determination of unsteady static pressure at the rotor blade surface, which will define the blade loading and edge velocity of the blade boundary layer. Finally, unsteady blade surface heat-transfer measurements will be acquired.

Acknowledgments

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Advanced Multistage Turbine Blade:

Aerodynamics

Performance

Cooling

Heat Transfer

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OBJECTIVE

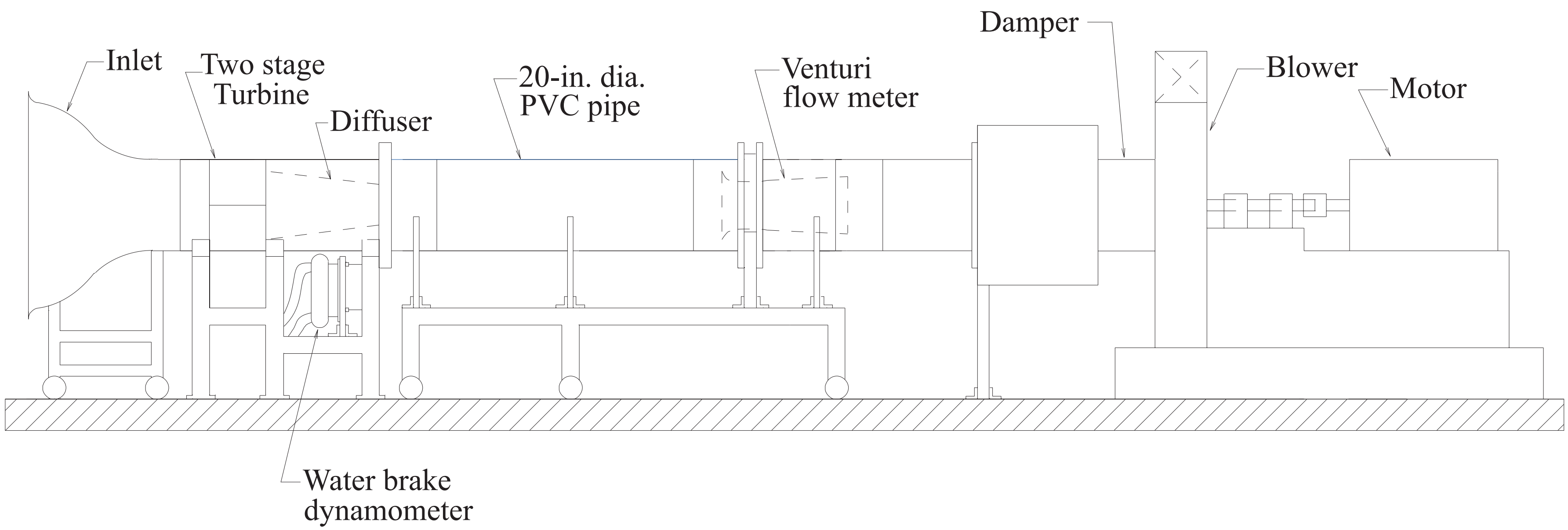
Advance Blading Designed by Allison

Investigate the 3-D, unsteady flow and heat transfer phenomena which control the performance of advanced turbines...

PAYOFF FOR ATS

Improve the design capability for high temperature turbines by providing a thorough, detailed understanding and data base of the steady and unsteady turbine flow and heat transfer

Facility:
Purdue Low Speed Research Turbine

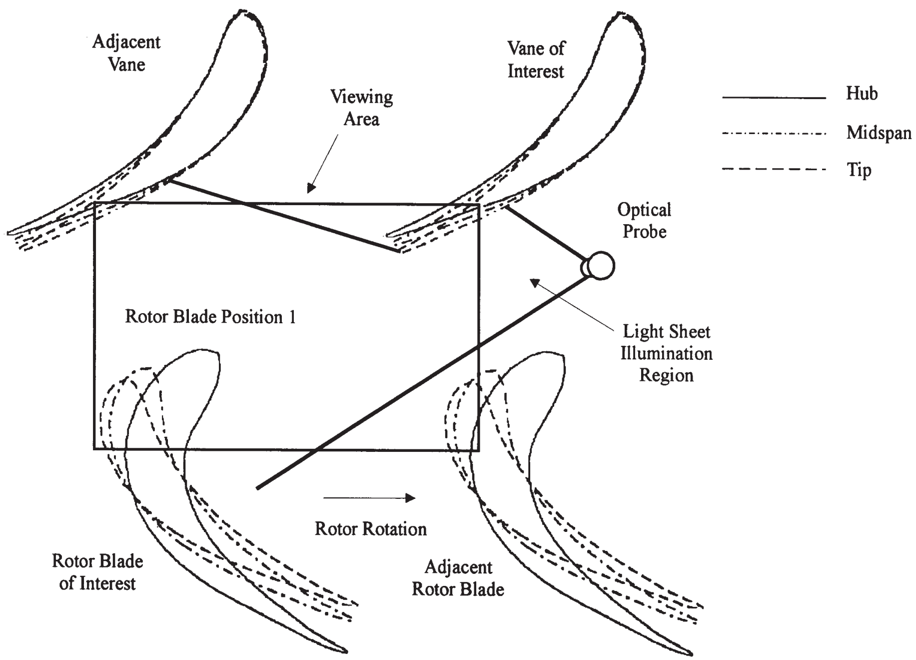


Purdue Research Turbine

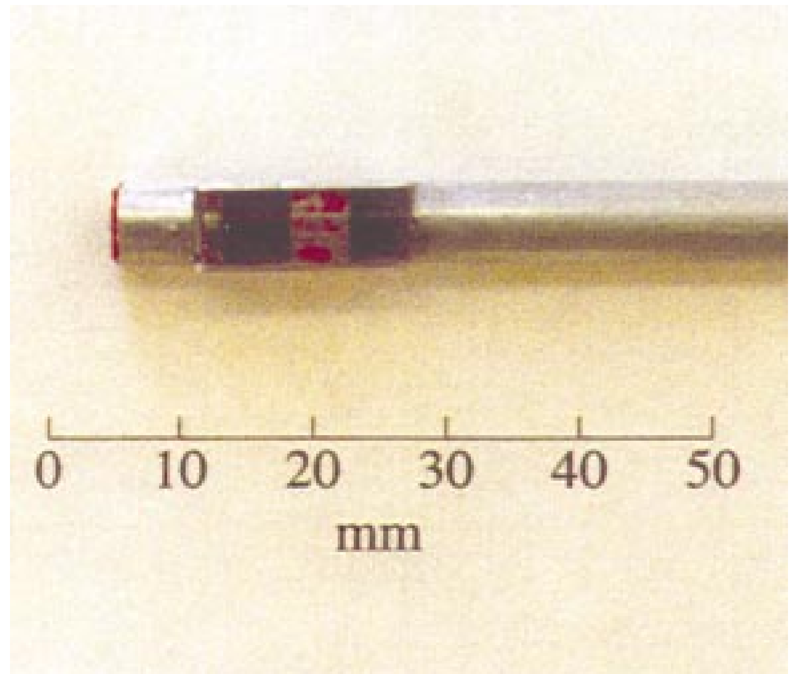

PURDUE

PIV Measurements

Measurements of first vane flow and vane-rotor interaction have been completed. Included are the effects of rotor pass and spanwise variation on the flowfield upstream of the first rotor row

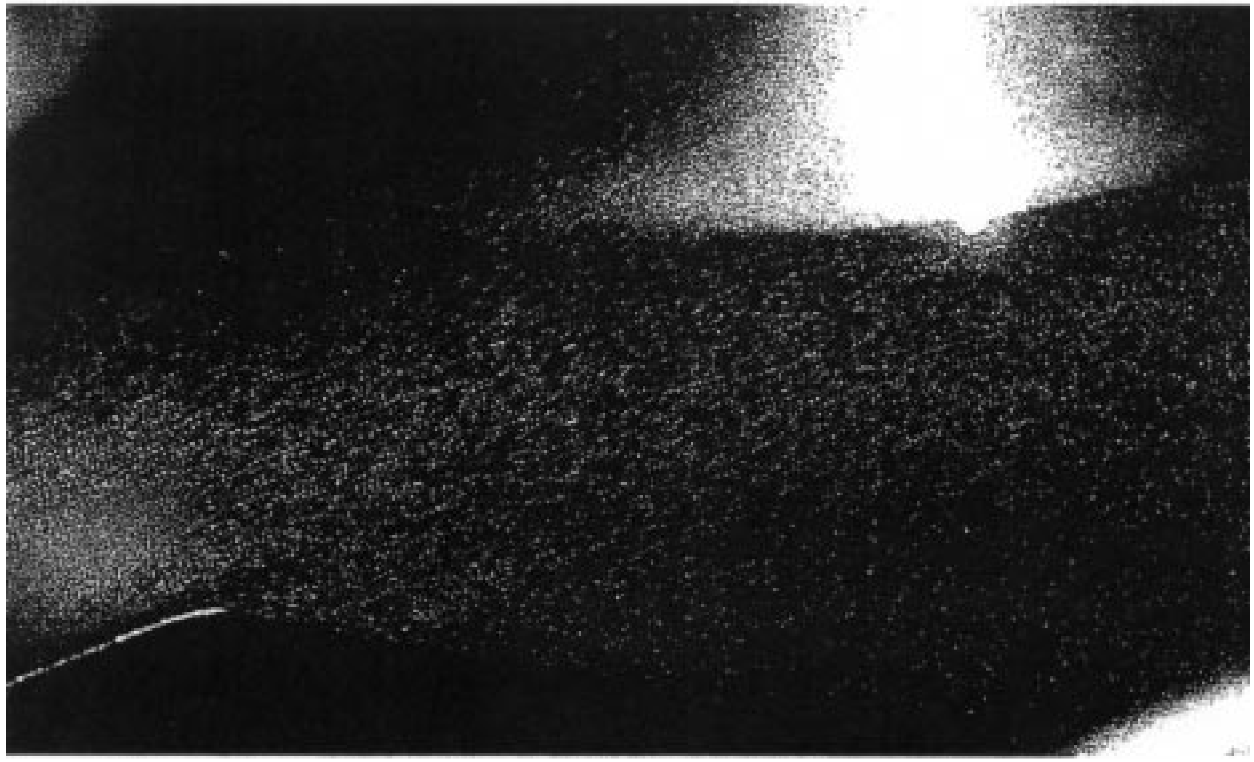


Vane-Blade Imaging Region

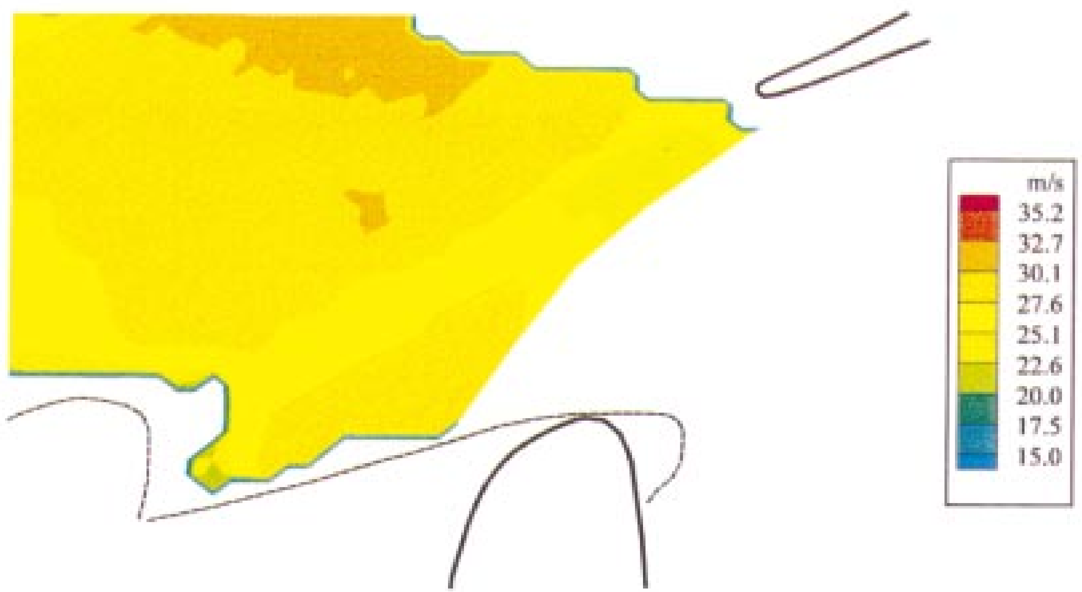


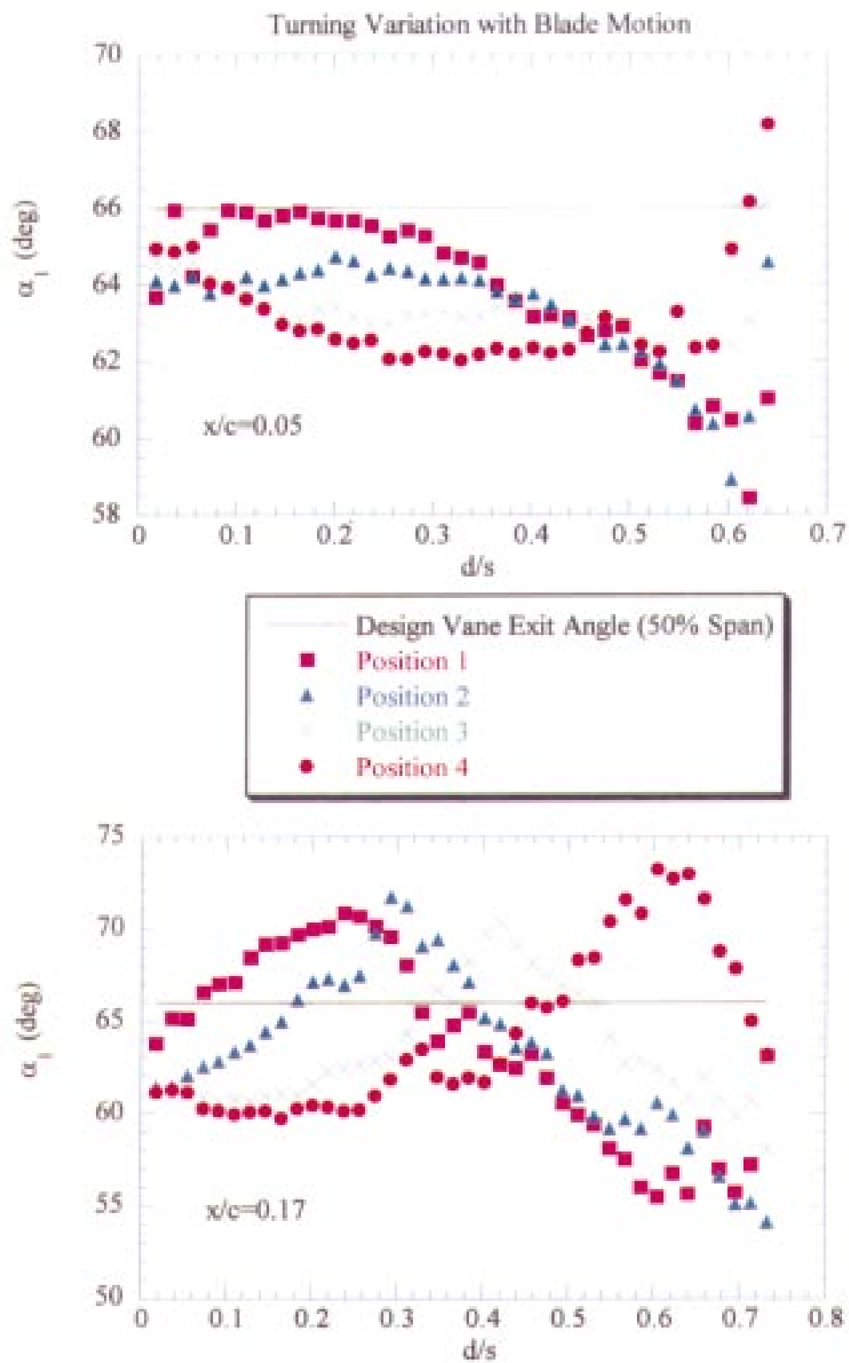
Light Sheet Probe

Raw PIV image of flow between first vane and first rotor



Ensemble average velocity magnitude at 50% span



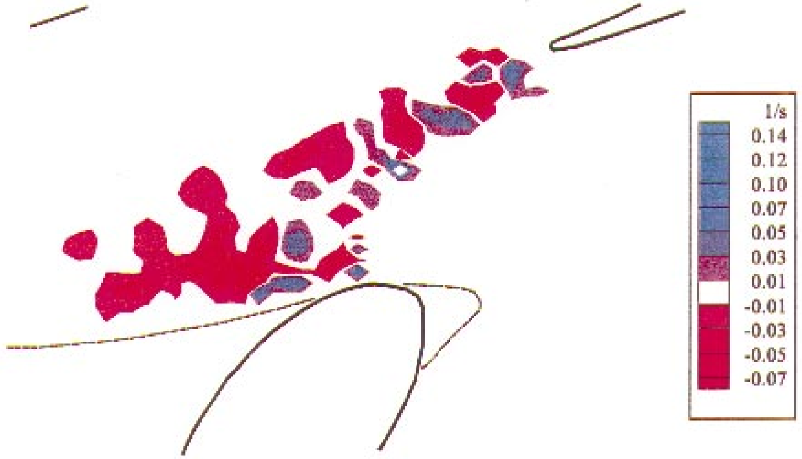


Vane exit absolute flow angle variation as rotor blade advances past vane

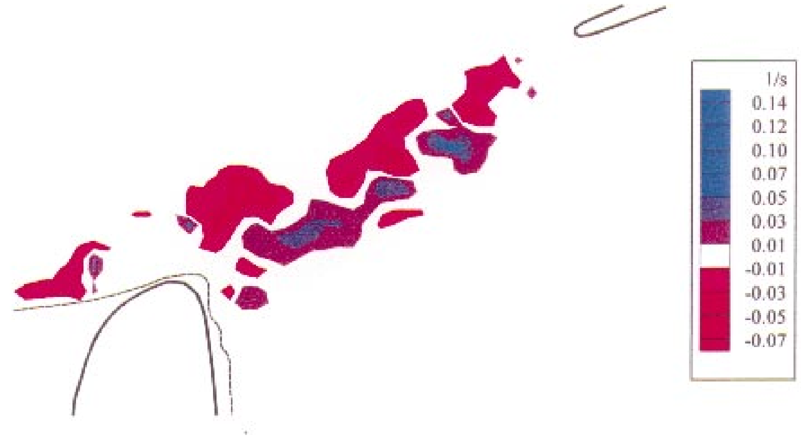
Close to vane trailing edge, rotor potential effects are minimal... wake dominates turning variation

Closer to rotor, the strong influence of the rotor potential field can be seen as turning variation tracks the rotor leading edge

Instantaneous Vorticity: Vane wake variation with span

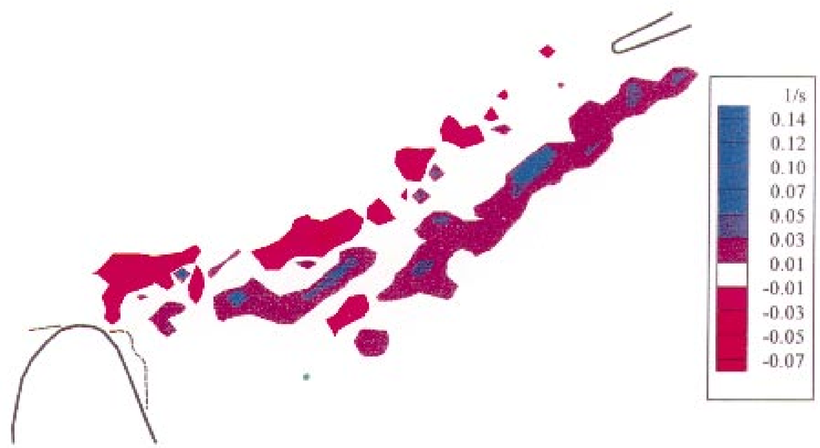


30% Span



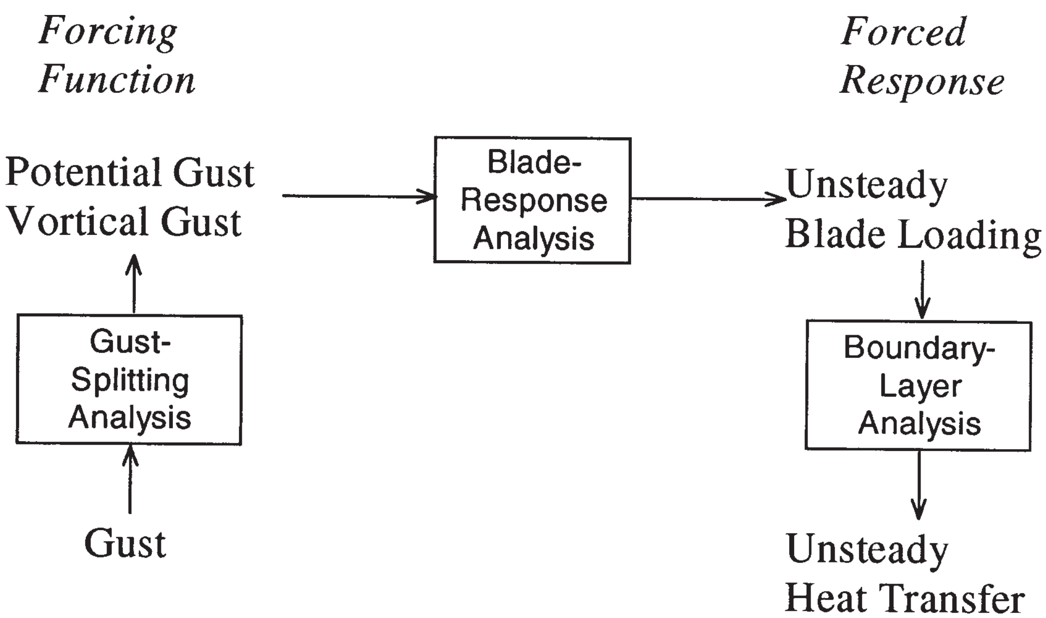
70% Span

50 % Span



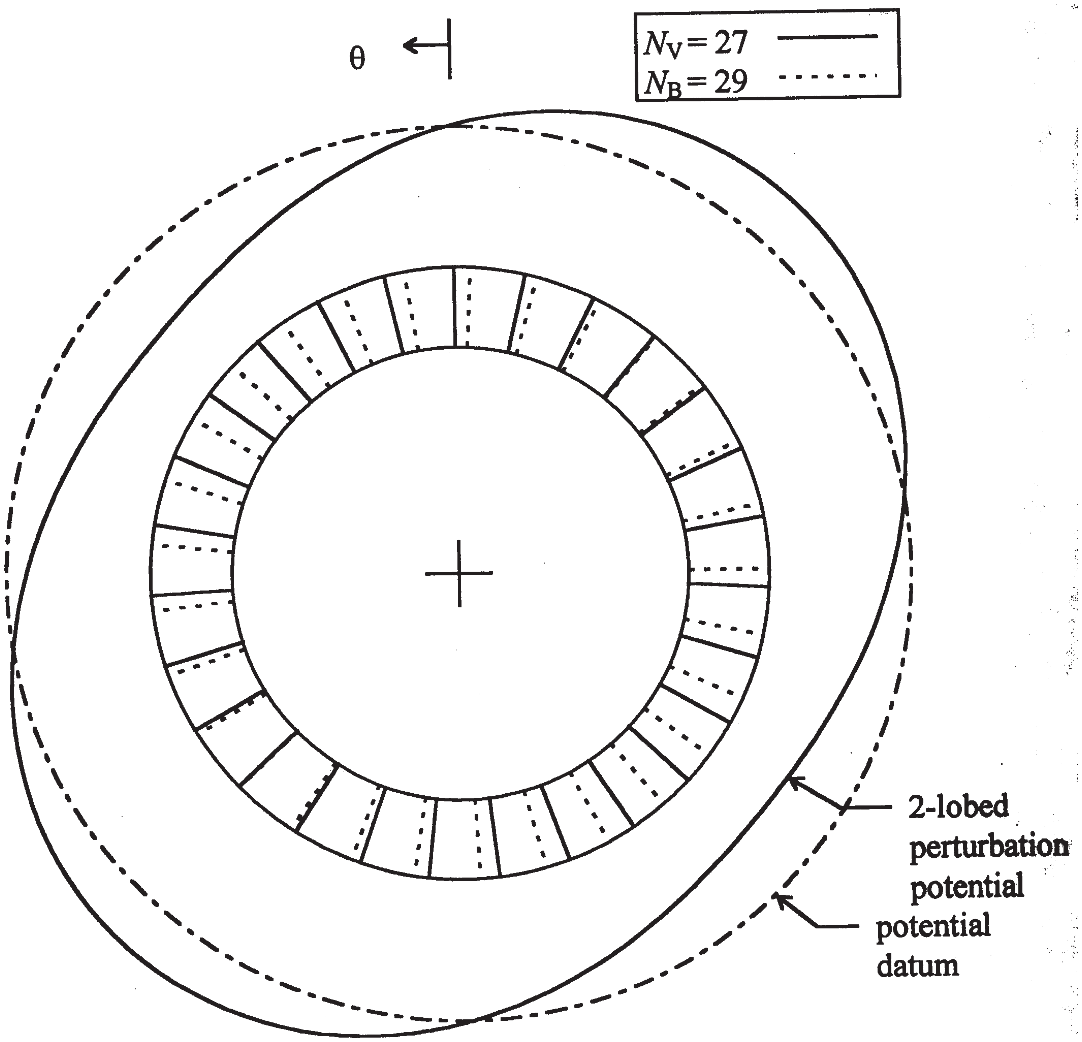
90% Span

Forcing Function Characterization



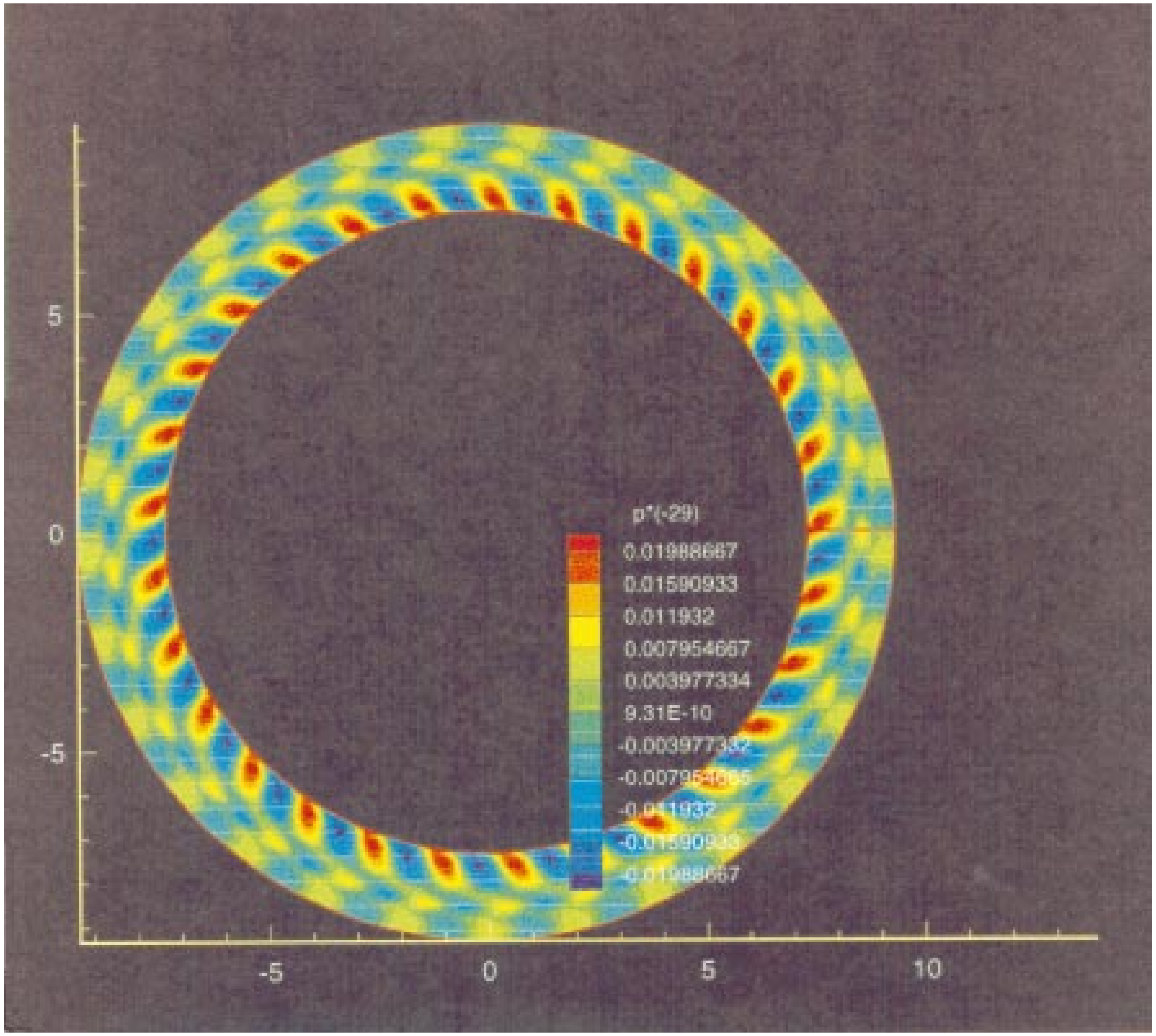
Quantification of the unsteady, 3-D forcing function for blade loading and heat transfer is required for verification of models developed under this program...

Interactions between rotor and stator blade rows cause acoustic fields to be generated. These "interaction modes" form a part of the unsteady forcing function

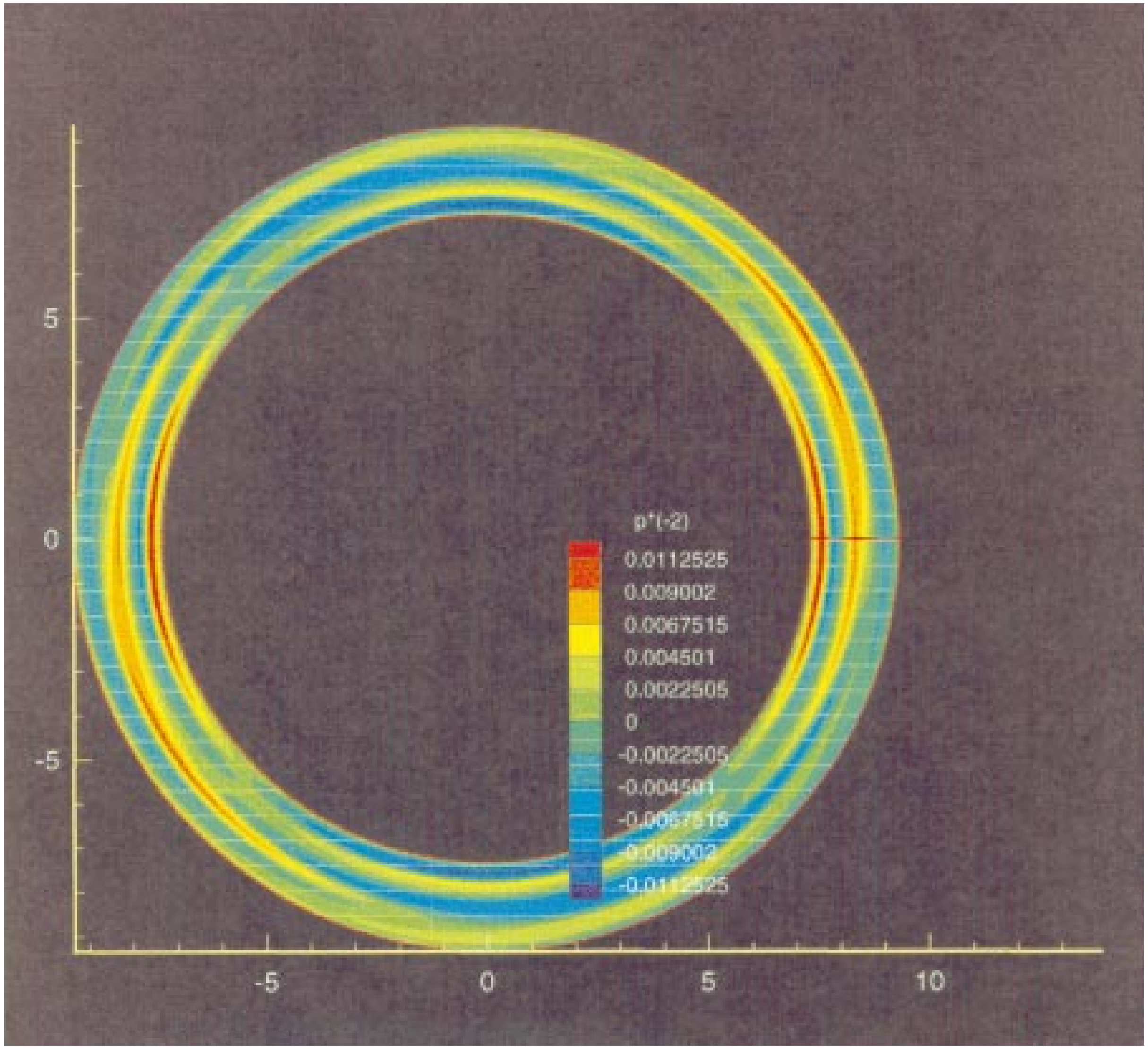


2-lobed blade-difference mode

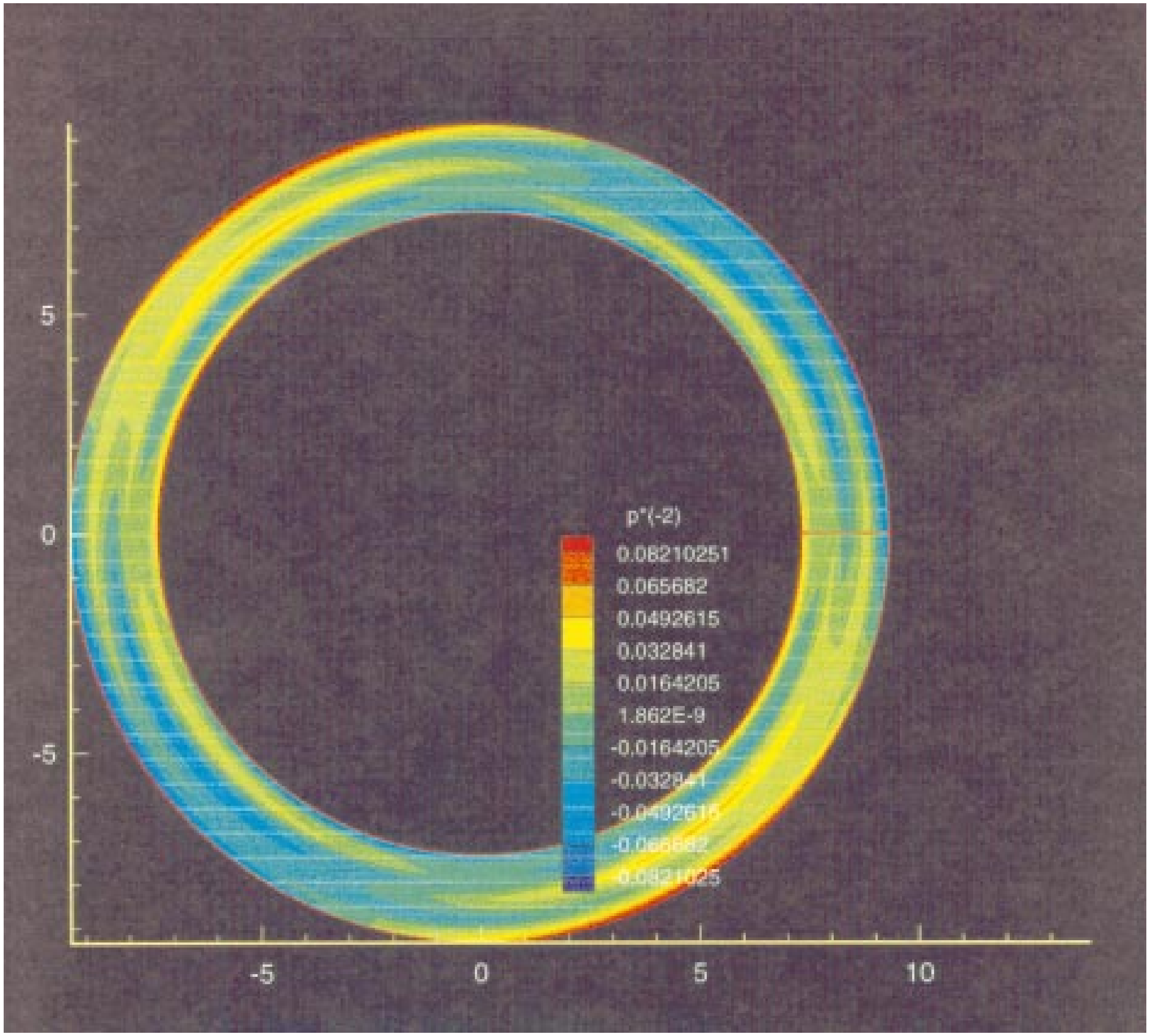
Blade-difference mode potential interaction is characterized by ensemble averaged point measurements of velocity and total pressure made upstream and downstream of the blade row



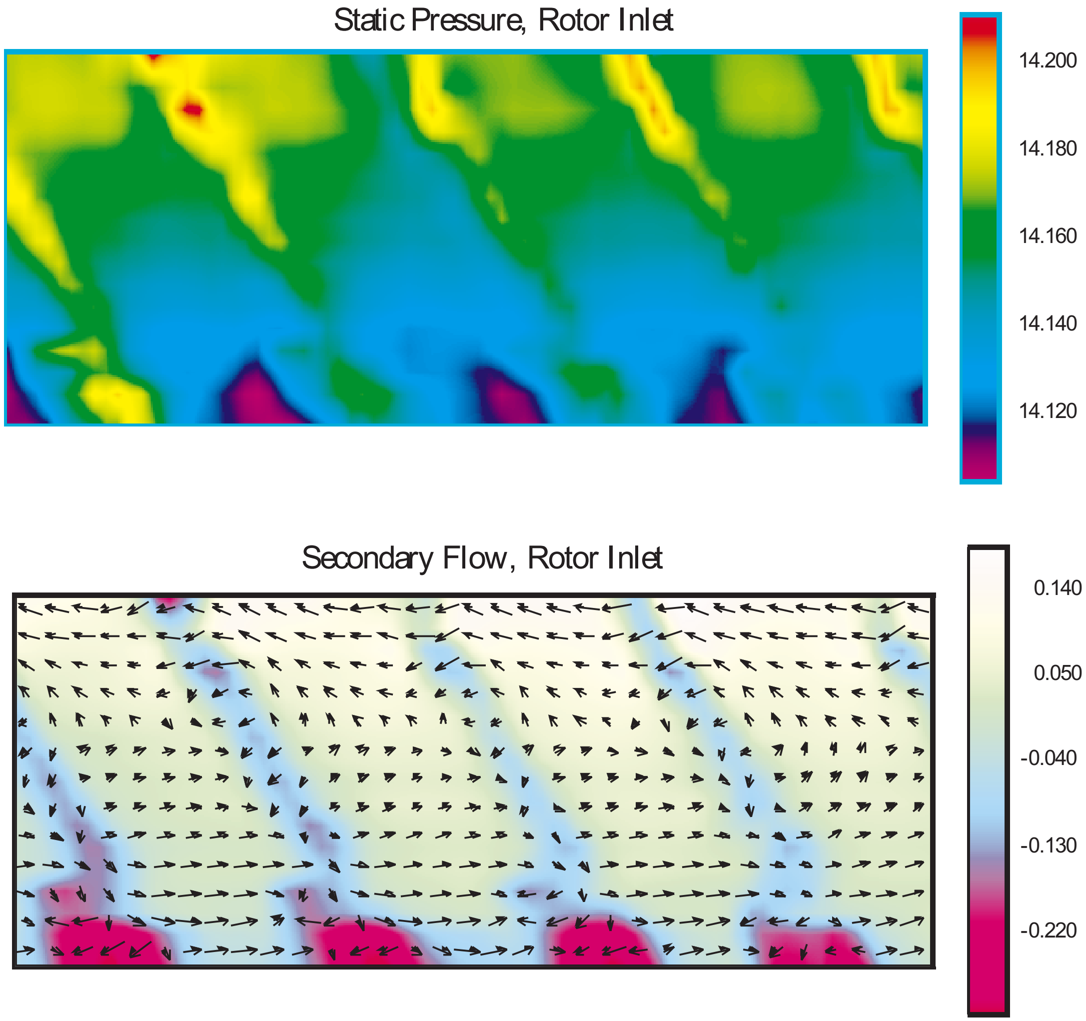
Blade mode static pressure field upstream of the rotor



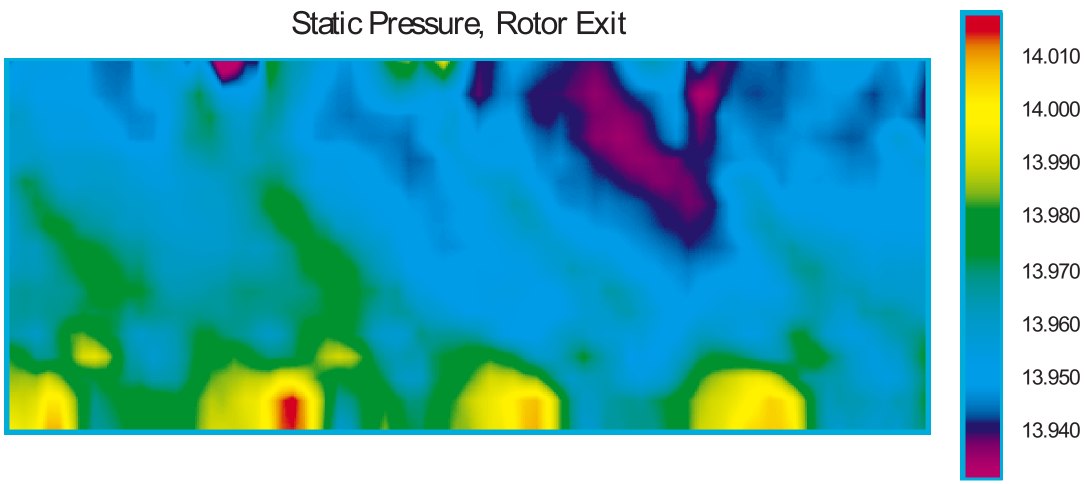
Blade difference mode static pressure field upstream of the rotor

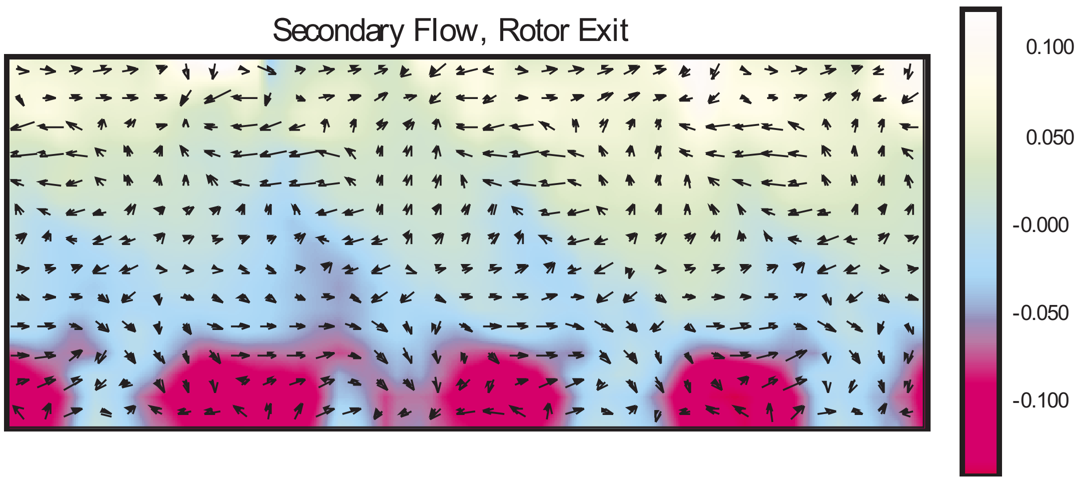


Blade difference mode static pressure field downstream of the rotor



Radial variations at the rotor inlet are characterized by 3-wire thermal anemometry and dynamic total pressure measurements.





Radial variations at the rotor exit are characterized by 3-wire thermal anemometry and dynamic total pressure measurements.

Summary

PIV measurements have characterized the vane-blade interaction event

The blade difference mode potential forcing function has been characterized

Radial variations of the forcing function to the first rotor row have been measured

The complete thermal and aerodynamic response measurements are now being completed